I. C. 6953

AUGUST 1937

DEPARTMENT OF THE INTERIOR

UNITED STATES BUREAU OF MINES
JOHN W. FINCH, DIRECTOR

INFORMATION CIRCULAR

HAZARDS OF COMPRESSED-AIR JETS FOR VENTILATING GASSY MINES

REC'D

BY

R. D. CURRIE AND L. L. NAUS

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HAZARDS OF COMPRESSED-AIR JETS FOR VENTILATING GASSY MINES[1]

By R. D. Currie[2] and L. L. Naus[3]

INTRODUCTION

Hazards in connection with the use of compressed-air jets for ventilating gassy mines are given little consideration by most mine officials largely because compressed air is considered the safest means of transmitting power for operating various types of mining machinery, and the inherent dangers in its use for this purpose are virtually negligible.

The installation of compressed-air lines in coal mines leads to the utilization of compressed air for ventilating working places, with the result that, although the primary ventilation systems may be adequate to meet existing needs, proper conduction of normal ventilation has been neglected, so the working faces receive only a small amount of the total air circulated through the mine.

Reliance in part on compressed air or other auxiliary means for ventilation is always attended by danger that gas will accumulate, due to intermittent operation, and the tendency is to operate auxiliary schemes only during the working shift (or possibly only part of the shift) and to dispense with them during off-shifts or at times during the working shift when gas may accumulate because of lack of ventilation.

When the men come on shift the auxiliary ventilating device often may be started without a preliminary examination of the working place, or if the examination may be made sometime before the oncoming shift arrives, the gas being allowed to accumulate in the meantime. This may result in uncontrolled movement of a body of gas if proper precautions are not taken. Several mine explosions have been caused by the movement of a known body of gas by compressed air into the haulageway, where it was ignited by an arc from a passing locomotive. This danger is more pronounced where supervision is lax.

The high velocity of compressed air escaping from jets, open valves, or open-end supply lines may cause a decided churning action, which serves to

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mix more intimately any liberated gas or dust and greatly increases the danger of ignition from these sources. It also tends to maintain dust in continual suspension, which cannot be other than detrimental to the workman. High-velocity compressed air issuing from jets may create channels through gas accumulations in such manner as to remove or dilute only a part of the accumulations, leaving much of them to be ignited later.

Experience has shown that the common methods of using compressed air for ventilating mines are extremely hazardous, in addition to which it has generally been accepted that they are inefficient and ineffectual. The following accidents, in which compressed air used for ventilation was directly responsible for accumulation of gas, are representative of scores of such accidents reported to the Bureau of Mines:

1. A gas explosion occurred at an anthracite mine on January 10, 1936, as the direct result of using compressed air for ventilation.

A 3/4-inch pipe, swaged down to a 1/16-inch opening and supplying compressed air at approximately 55 pounds pressure, was being used to ventilate a slant heading between two breasts being driven on a 45° pitch. The slant was about 300 feet from the gangway.

The board manway brattice was loosely constructed and too far back from the face of the breast to supply ventilation in the proper manner, and the compressed air jet was about 15 feet back from the face.

A safety lamp carried by the miner had been extinguished by an explosive mixture of methane and was being held at the nozzle of the jet to clean out the lamp and cool it; at the same time the igniter was used to relight the lamp. An explosion occurred that resulted in the death of the two men in the place.

This lamp was tested in a McCaa lamp-testing box immediately after the explosion; no explosion could be produced with it in the tests. The conditions prevailing at the time of the explosion were duplicated as nearly as possible in tests conducted by the Bureau of Mines, and it was found that a properly assembled flame safety lamp of permissible type will ignite explosive gas under such conditions.

This practice of cleaning out and cooling flame safety lamps with the compressed-air jet is decidedly hazardous although quite common in some sections of the anthracite field.

2. On April 19, 1909, upon detecting gas at a working face in a coal mine in Ohio, a fire boss opened a compressed-air valve to ventilate the place and left. No danger board was erected, and a man wearing an open light entered the place and ignited the explosive mixture.

3. On June 28, 1927, nine men were badly burned at a mine in Alabama by an ignition of gas caused by an arc in the 110-volt light circuit about 12 feet back from the upper end of a slope that was being driven.

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Methane accumulated after the rock-drill compressor supplying the only means of ventilation had been shut off, as was customary, for 4 hours just before the men came on shift.

4. On November 14, 1927, a raise driven off the engine room to the coal seam in a bituminous coal mine in Washington was giving off gas at the face. A compressed-air hose was used to supply ventilation and to prevent the accumulation of the gas. While making his rounds, the fire boss found gas filling the raise and extending nearly to the haulageway. The compressor was shut down and the place fenced off by the fire boss, who then waited the arrival of the mine foreman to receive further instructions. The fire boss was instructed to blow the gas out by using compressed air. He had started to do this when a passing locomotive ignited the gas, with the result that four men were burned, one of whom died later.

5. On April 12, 1930, 17 men were killed by a gas explosion at the above-mentioned mine. This explosion happened in a chute that was ventilated by compressed air and a ventube blower, and at least two of a series of holes were overcharged with permissible explosives. The shots were fired in multiple with a 500-volt trolley wire.

Coal dust no doubt was thrown in suspension; gas probably was present or was released by the blast of the first shot, and the flame, presumably from the detonation of the overcharged second shot, ignited the dust, gas, or both.

6. An explosion that occurred at a gassy bituminous mine in Utah on March 8, 1930, burned seven men, with the result that five of them died and the other two were injured seriously.

The fan was not running at the time of the explosion. Under normal working conditions the fan was run only intermittently and natural ventilation was supposed to ventilate the mine when the fan was not in operation.

Compressed-air jets were used to ventilate the working places and no line brattice was carried to the face. It is probable that the explosion was caused by ignition of an accumulation of gas by a spark or arc from a nonpermissible mining machine. As water was used on the cutter bar, it is not likely that coal dust played more than a minor part in this explosion.

7. On June 21, 1933, an explosion occurred at a bituminous coal mine in Oklahoma which resulted in the death of the mine foreman and one of a group of four rescuers.

The explosion was the result of use by the mine foreman of a compressed-air hose to clear gas from a vertical cut before blasting. The mixture of gas with coal dust, raised in suspension while the kerf was being cleaned, probably was ignited when the foreman attempted to light the shot with a match.

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8. On January 12, 1935, an accident occurred in the sand blasting department of a California manufacturing company, which caused the death by carbon monoxide of one of three sand-blast operators, who were furnished ventilation to sand-blast masks from a 5,000-cubic-foot compressor through a 1/4-inch heavy hose. One operator detected a strange odor and left his compartment to check with the other two. He found one of them absent from his compartment and the other dead from carbon monoxide poisoning.

Due to a broken exhaust valve, the compressor became unduly heated and set fire to oil and carbon, and the carbon monoxide liberated was carried through the hose to the masks.

These accidents, in which the use of compressed air for ventilation was directly involved, indicate that it is not a safe means of ventilation, at least in coal mines, which give off explosive gas, and at best is a decidedly costly method per unit of volume of air furnished or moved.

Another hazard in connection with the use of compressed-air jets in gassy and dusty mines is that of possible static sparks. Although this hazard has not been recognized in this country, it has been given considerable thought and study in Europe, as indicated by the following information.

In Belgium and France firedamp explosions have occurred during the dispersal of gas accumulations by compressed air, the ignitions having been credited to electrostatic charges generated at the nozzle by the issuing air[4].

Tests made by passing clean or dust-laden compressed air through an iron tube at different velocities (20 to 50 meters per second) and pressures (4 to 8 atmospheres) revealed that the dust particles and the nozzle with supplementary fittings acquired opposite and equal electrostatic charges.

Due to friction along the walls of the tube, compressed air alone gave potentials of only 20 volts, while dust-laden air gave potentials of several thousand volts. When the air is humid, a mist is formed in front of the nozzle and electrostatic charges are not likely to be produced.

Conditions most favorable to the generation of these charges were dry nonagglomerating dust in a concentration of about 200 grams per cubic meter; dry compressed air; air velocities over 20 meters per second; dry, warm, low-ionizing air surrounding the charged particles; and a satisfactory insulation.

The intensity of spark required to ignite gas was studied on a gas mixture containing 7 to 8 percent of methane; in dry warm weather ignition was obtained in each test within a few seconds after turning on the compressed air. In damp weather an ignition was much more difficult to obtain, owing to the amount of moisture in the atmosphere and its high state of ionization.

4/ Iron and Coal Trades Review: Electrostatic Charges Generated by Compressed Air, November 24, 1933, p. 797.

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Although the tests showed that the sparks will cause ignition, it is concluded that the requisite conditions for an ignition occur rarely in underground workings. In cold weather, electrostatic charges may be produced underground at compressed-air nozzles. It also may be assumed that the air in dry, hot workings will have a low conductivity, and thus favor the generation of electric sparks.

As the compressed-air mains are usually sufficiently grounded, no high potentials can be produced by them. The danger lies in well-insulated metallic parts.

The pipes used to clean boreholes, especially if joined to the supply by a rubber pipe or hose, are a source of serious electrostatic charges and hence may be the possible cause of ignition. Grounding the metal pipes will obviate all danger.

Experiments have shown that enough electricity can be generated by the friction of a small pulley and belt (such as booster fan drives) to ignite natural gas readily.

Static electrical charges of rather high potential are sometimes generated by leaks in steam and air lines. These charges are equalized by sparks jumping from the charged cloud of steam or air, which may be of sufficient intensity to ignite a mixture of methane and air. It is not definitely known whether such a spark could ignite coal dust.

The following table gives the discharge of air from small orifices; these figures have been used to calculate the flow from jets under conditions observed in the anthracite region of Pennsylvania.

Gage pressure, pounds	Discharge, cu. ft. of free air per min. Diameter of orifice, inches 5/		
	1/16	1/8	1/2
40.....	3.07	12.3	196
45.....	3.36	13.4	215
50.....	3.64	14.5	232
60.....	4.20	16.8	268
70.....	4.76	19.0	304
80.....	5.32	21.2	340
90.....	5.87	23.5	376
100.....	6.45	25.8	412

Under average conditions of pitch, height, and width, the minimum quantity of air necessary to ventilate properly a gassy, two-man, working place is 400 cubic feet per minute. A compressor with a capacity of 2,000 cubic feet of free air per minute would be capable of supplying compressed air to only five such working places.

5/ Peele, Robert, Mining Engineers' Handbook, 1927, p. 1090.

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The proper ventilation of a gassy mine, or portion of such a mine, solely by compressed air is not practicable because of the prohibitive cost. At 3 cents per 1,000 cubic feet for compressed air, which is probably a fair average, the cost of ventilating a gassy mine of five two-man working places for 8 hours would be $28.80. To ventilate a moderate sized gassy mine of 100 two-man working places by compressed air would cost a minimum of $576.00 per 8-hour day.

Based on the preceding table, the cost of using compressed-air jets is as follows:

Gage pressure, pounds	Cost per hour, cents		
	Diameter of orifice, inches		
	1/16	1/8	1/2
40	0.55	2.21	35.28
45	.61	2.41	37.70
50	.66	2.61	41.76
60	.76	3.02	48.24
70	.86	3.42	54.72
80	.98	3.82	61.20
90	1.06	4.23	67.68
100	1.16	4.65	74.16

During 1932, 43,826,027 tons of coal were produced in the Pennsylvania anthracite region by 94,210 underground employees working an average of 157.5 days per man. The average production per underground employee was 2.9 tons per day.6/

A gassy mine operating five two-man working places would produce 29 tons of coal per day; if this mine were ventilated by compressed air at a cost of $28.80 per day, the cost of ventilation per ton of coal produced would be 99.3 cents. On the other hand, the cost of ventilation by a small unit fan and galvanized iron tubing is 0.03 cents per 1,000 cubic feet7/, or 0.993 cents per ton, based on the above fitures of production. Hence, this unit cost of supplying compressed air is about 100 times as great as the cost of supplying the same quantity of air by fan ventilation.

Although it is apparent that no company would attempt to use compressed air to ventilate a mine entirely, there are mines in which compressed-air jets, open-end compressed air lines, and other subterfuges for adequate ventilation are used or are permitted to be used. It is believed that such practices are the result of failure of mine officials to conduct the ordinarily sufficient, normal ventilation to the working places by properly maintained brattice or to follow a seriously considered ventilation program.

6/ Adams, W. W., and Geyer, L. E., Coal-Mine Accidents in the United States, 1932: Bull. 380, Bureau of Mines, 1934, 87 pp.

7/ Harrington, D., Metal-Mine Ventilation and Its Relation to Safety and Efficiency in Mining Operations: Report of Investigations 2133, Bureau of Mines, 1920, 8 pp.

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A recent study has revealed that use of reducer nozzles or jets at the end of supply lines is common practice in anthracite mines. Jets of 1/2-inch opening were found on gangways where the compressed air was used for several hours after blasting; jets of 1/8-inch opening were used in chutes and breasts and were allowed to remain in use at all times (in some instances, even on idle days); jets were sometimes found inserted in 5- by 6-inch wooden tubing (inside measurement) about 6 feet long, producing an injector effect; usually, however, they were connected to the supply line without the tubing and too far back from the face to be of benefit.

Although compressed-air jets in a box or tube created an injector effect and circulated a considerably larger quantity of air, in virtually every instance the result was recirculation of the air in the working place.

One installation consisted of three 1/16-inch jets spaced about 100 feet apart along the supply line in a pillar hole that had been driven about 430 feet. The pressure on the line was about 40 pounds, so that the maximum free air delivered from the three jets could not exceed 10 cubic feet per minute.

At another place on a gangway, a 1/2-inch jet inserted in the end of metal tubing 24-inches in diameter and 100 feet long extended from the gangway door about 135 feet outby the face. The quantity of air delivered at the inby end of the tubing was 1,866 cubic feet per minute, of which 376 cubic feet was delivered from the compressed-air line, according to the table for a 1/2-inch jet at 90 pounds pressure.

A similar installation consisted of a 1/8-inch jet inserted in the end of metal tubing 8 inches in diameter leading from the gangway to the working place through a rock hole. In this instance the 8-inch metal tubing had an extension of 5- by 6-inch wooden tubing. The quantity of air delivered in this instance was 466 cubic feet per minute, of which 24 cubic feet was supplied by the jet, according to the table for a 1/8-inch jet, at a pressure of 90 pounds.

Other methods for ventilating by compressed air consisted of open or partly open valves and open-end supply lines, which sometimes were inserted in one end of a 6-inch length of wooden tubing.

As commonly used in mines, ventilation by compressed-air jets, open valves, and open-end supply lines is neither efficient nor effective; because of the high velocity of the escaping air and the turbulent action created, it requires at least 6 volumes of compressed air to remove 1 volume of smoke such as is created by blasting. On the other hand, 1 volume of fresh air conducted to a working place by means of a properly constructed brattice so as to maintain a velocity of about 25 feet per minute, will remove easily 1 volume of smoke.

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An adequate and dependable ventilating system precludes the necessity of secondary ventilation schemes such as compressed-air jets, open valves, and open-end compressed-air supply lines. In general, it will be found that wherever compressed-air lines are installed there is a tendency on the part of the men to use the compressed air in an effort to clear away the smoke from blasts and for ventilating purposes, simply because the ordinarily sufficient, normal ventilating current has not been maintained properly. When compressed-air jets, booster fans, and ventube blowers are used or are permitted to be used in normal mining operations, it is essentially a confession on the part of the mine officials that their primary ventilating system is inadequate or undependable.

Some companies have taken definite steps to eliminate the costly and wasteful use for ventilation of compressed air for power tools. A reducer (shown in figure 1) has been installed by one company at all junction lines where compressed air is used for drilling; this limits the amount of air allowed to escape should the valve be left open after the jack-hammer is disconnected.

The valve shown in figure 2 apparently is a better, although more costly, means of eliminating leakage. When this valve is installed in the compressed-air line, the only leakage possible is through the very small bypass opening in the valve, which allows a back pressure to build up against the valve until the pressure on each side of the valve stem is equalized when a jackhammer is connected to the end of the line. The adjusting spring is set so that the valve remains open while the jackhammer is connected. As soon as the connection is broken, the pressure on the supply side of the valve causes the stem to seat and shut off the flow of air, except the small quantity that flows through the bypass opening. The valves are adjusted and sealed in the shop so that they cannot be disturbed; in case they fail to function properly they are sent back to the shop for repair.

There are places and conditions that may justify the use of secondary ventilating aids, as in prospecting, starting new places, cleaning sumps, driving rock tunnels, or sinking or raising shafts.

Under such conditions comparatively safe and efficient methods of using compressed-air power for driving ventilating machinery are compressed-air-driven fans, blowers, and injectors.

These devices, however, should be placed so that they do not recirculate the mine air and will be in an air stream of at least four times their capacity, or are bratticed off in such a manner as to preclude the possibility of recirculation.

These secondary ventilating aids should be kept in operation at all times to guard against dangerous accumulations of gas that may develop while auxiliary ventilators are idle, and to prevent the uncontrolled movement of bodies of gas when the fans, blowers, or injectors are started.

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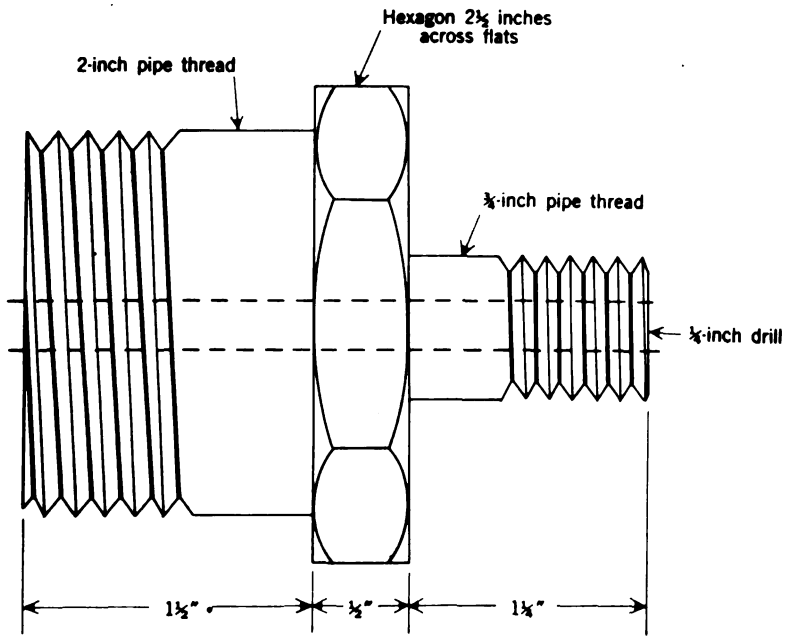

Figure 1.—Reducer for compressed-air line.

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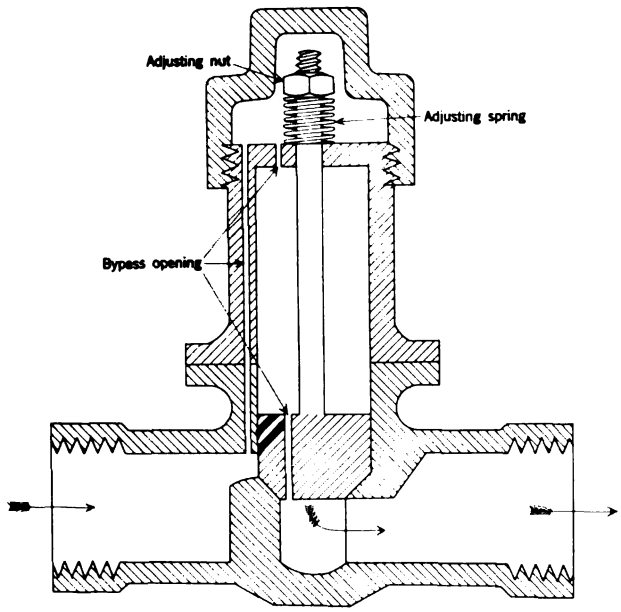

Figure 2.—Valve for compressed-air line.

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The use of jet installations for ventilating by compressed air affects only that portion of the working place in the immediate vicinity of the escaping air. A slight cooling effect could be felt, but rarely at a distance more than a few feet from the jet.

Compressed-air jets may be used occasionally for temporary service or in emergencies in shafts, where a number of jets fed by one air line may be placed either at the top or bottom of the shaft. Used in this manner they act as a propulsive force only. Steam jets may be used for this purpose, also, and to somewhat better advantage. Placed at the bottom of the shaft, the steam reduces the density of the upcast column of air and acts as a propulsive force. Based on fuel consumed, the efficiency of the steam jet is probably not over 15 percent, and the total efficiency of compressed-air jets used in this manner is even lower.

CONCLUSIONS

Compressed-air jets are inefficient and ineffective means of ventilating gassy mines; their use in mines of this class constitutes a confession that normal ventilation is inadequate. Conclusive evidence that compressed-air jets and blowers are hazardous is found in reports of accidents that were directly or indirectly the result of efforts to ventilate with compressed air. A few of these cases were cited in this paper, and the cost of ventilating by compressed-air jets, compared with ventilation by more effective devices or methods, proves that the management is lax at operations where their use is permitted. More progressive companies not only prohibit the use of compressed-air jets for ventilation but insert valves or controls in the lines, which prevent the miners from using them even if they desire to do so.

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